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<p>(21) International Application Number: PCT/GB87/00434 (22) International Filing Date: 22 June 1987 (22.06.87) (31) Priority Application Number: 8615196 (32) Priority Date: 21 June 1986 (21.06.86) (33) Priority Country: GB (71) Applicant (for all designated States except US): RENISHAW PLC [GB/GB]; Gloucester Street, Wotton-under-Edge, Gloucestershire GL12 7DN (GB). (72) Inventor; and (75) Inventor/Applicant (for US only) : STEPHENS, William, Frank, Noel [GB/GB]; 2 Sandpits Lane, Hawkesbury Upton, Badminton, Gloucestershire (GB). (74) Agents: WAITE, J. et al.; Patent Department, Renishaw plc, Gloucester Street, Wotton-under-Edge, Gloucestershire GL12 7DN (GB).</p>		<p>(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent), US. Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>
<p>(54) Title: OPTO-ELECTRONIC SCALE READING APPARATUS</p>		
<p>(57) Abstract</p>		
<p>Opto-electronic scale reading apparatus comprising a read head (10) in which a plurality of optical emitter and receiver pairs (15, 25) are arranged so that beams (13) of collimated light generated by the respective emitters (15) fall on a common region (30) of a scale (11). Compared to arrangements where the light beams fall on separate regions of the scale, the apparatus according to the invention is relatively immune to the effects of certain misalignments between the scale (11) and the read head (10).</p>		

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OPTO-ELECTRONIC SCALE READING APPARATUS

This invention relates to opto-electronic scale reading apparatus of the kind comprising a scale defined by spaced lines, a read head, the read head and the scale being relatively movable in the direction of spacing of
5 the lines; a plurality of units embodied in the read head and each comprising a light emitter for illuminating a region of the scale, a light receiver for receiving light from the illuminated region, grating means arranged in
10 the light path between the emitters and the receivers for producing in respect of each unit a light modulation corresponding to the relative movement of the scale and the read head, wherein the light modulations of the
15 respective units occur in phase-shifted relationship. The phase-shifted relationship is required for determining direction of movement and, possibly, position interpolation between scale lines.

Such an apparatus is known generally from GB 1,504,691 wherein the light modulations are in the form of moire fringes and wherein the units are positioned to read the fringes in phases separated by 90° . The units are
5 positioned to read the respective phases from different portions of the scale lines along the length thereof. As a result, if there is any yaw misalignment between the read head and the scale, the resulting moire error leads to a significant phase error with consequent difficulty
10 regarding interpolation. Yaw misalignment is angular misalignment about an axis normal to the length and to the direction of spacing of the scale lines. A moire error is an error in the period of the moire fringes. A phase error is said to occur if the phase separation
15 between said units differs from their nominal value of 90° .

Also, since the known apparatus reads the respective phases from different portions of the scale lines along
20 the length thereof, the apparatus is sensitive to variations in such parameters as straightness, parallelity and reflectivity along the length of those lines.

25 The foregoing difficulties are reduced or avoided by the apparatus claimed in Claim 1 hereto and characterised in that the respective units are positioned so that the light emitters illuminate a region of the scale which is substantially common to all said emitters.

30 Embodiments of apparatus according to this invention will now be described with reference to the accompanying drawings wherein:-

Fig. 1 is a sectional view a first embodiment of the apparatus.

5 Fig. 2 is a section on the line II-II in Fig. 1 and an associated circuit diagram.

10 Fig. 3 is a diagram for explaining the vector geometry associated with the above circuit diagram.

Fig. 4 is an expanded diagram representation of Fig. 3 and an associated phase diagram.

15 Fig. 5 is a view similar to Fig. 4 but shows a modification.

Fig. 6 is a sectional view of a second embodiment of the apparatus.

20 Fig. 7 is a sectional view of a third embodiment of the apparatus.

Fig. 8 is a view on the line VIII-VIII in Fig 7.

25 Fig. 9 is a view of a fourth embodiment.

Fig.10 is a view on the line X-X in Fig 9.

30 Referring to Figs 1 to 4, the apparatus is described with reference to the coordinates X,Y,Z of the orthogonal coordinate system. A read head 10 is movable relative to a scale 11 in the X-direction. The scale 11 comprises a body 16 having scale marks defined by lines 17 extending in the Y-direction and spaced in the X-direction. The
35 lines lie at an XY surface 18 of the scale 11. The read head 10 comprises a collimating system in the form of an

axisymmetric collimating lens 12 having an optical axis 12Z perpendicular to an XY plane. The lens 12 is arranged for its collimating side to face the scale 11. The other or focussing side of the lens 12 faces an array of three
5 light emitters 15 and three light receivers 25 all arranged about the axis 12Z in a common XY plane perpendicular thereto. In the present example the emitters 15 and receivers 25 are opto-electronic diodes. Each emitter 15 is substantially a point source of
10 divergent light and is spaced from the axis 12Z by a radial offset 15R. As a result the lens 12 produces an incident beam 13 of collimated light projected along an axis 13R toward the axis 12Z. It will be clear that, by virtue of the offsets 15R, the axes 13R associated with
15 the respective beams 13 intersect at a common point 30P and the beams 13 intersect at a common region 30 lying in an XY plane. The relative position of the read head 10 and the scale 11 in the Z-direction is such that the region 30 lies at the surface 18. The incident beams 13
20 are reflected by the scale 11 to produce reflected beams 14 having axes 14R. The lens 12 focusses the beams 14 on to the respective receivers 25 which are spaced from the axis 12Z by radial offsets 25R corresponding to the offsets 15R.

25

It may be said that the emitters 15 define a group of emitting devices having the lens 12 in common, and that the receivers 25 define a group of receiving devices having the lens 12 in common. In the present example the
30 lens 12 is common to both said groups.

As shown in Figs 2 and 4 there are three pairs of associated emitters and receivers denoted 15A, 25A; 15B, 25B; 15C, 25C, wherein the two elements of each pair, e.g. 15A, 25A, are situated on diametrically opposite
35 sides of the axis 12Z as required by the lens 12. In the present example the emitters and receivers are arranged

- so that the emitters are spaced along a line 15X extending in the X-direction at one side of the axis 12Z and the receivers are correspondingly spaced along a line 25X in the X-direction at the other side of the axis 12Z.
- 5 Each pair of emitters and receivers 15,25 is associated with a pair of gratings 35,45 situated respectively in the projected and the reflected beams 13,14 between the lens 12 and the scale 11. Thus there are three grating pairs 35A,45A; 35B,45B; 35C,45C, associated respectively
- 10 with the emitter and receiver pairs 15A,25A; 15B,25B; 15C,25C. The gratings 35,45 lie in a common XY-plane and are defined by lines 37,47 which are parallel to the lines 17 of the scale.
- 15 Each pair of emitters and receivers 15,25 and the associated pair of gratings 35,45 are referred to as a phase unit 46. Each phase unit 46 is designed so that, during said relative movement of the scale and the read head, the relevant receivers 25A,25B,25C see respective
- 20 sinusoidal light modulations M, respectively denoted MA,MB,MC, produced by the optical interaction of the scale 11 with the gratings 35,45 of the respective unit 46. The modulations M have a period which is constant with respect to the pitch of the scale lines 17.
- 25 However, each modulation M may be regarded as a moire fringe manifest as the alternation of light and dark distributed over the aperture of the receiver. So long as the lines 17,37,47 are absolutely parallel the period of the moire fringes is said to be equal to infinity.
- 30 Otherwise that period is finite.

The gratings of each grating pair 35,45 have a phase separation which is offset from the corresponding phase separation of each of the other pairs nominally by 120° .

- 35 In other words the phase interval between any adjacent pair MA,MB or MB,MC or MC,MA is nominally 120° (Fig.4).

The receivers 25 have electrical outputs A,B,C which have the same phase separation as the modulations M.

- 5 The modulations M may be produced by optical interaction of the scale and the gratings as described in our International Application No. PCT/GB85/00600 or by any other such interaction.
- 10 The signals A,B,C are connected to a circuit 50 having differential amplifiers 51,52 for producing signal values B-A and B-C, and further differential amplifiers connected to produce signal values A-C and $2B-(A+C)$ which define respectively the sine and cosine terms of any one
- 15 of the signals A,B,C. The operation of the circuit 50 may be described as three-phase derivation of the sine and cosine terms of the light modulations independently of light level.. Four-phase derivation may be used but three-phases are more appropriate in the context of this
- 20 invention because it requires only three emitter and receiver pairs which are more readily accommodated in the aperture of the lens, compared to four such pairs normally required for four phases.
- 25 Referring to Fig. 3, the three outputs A,B,C are shown as vectors A1,B1,C1. The vectors A1 and C1 respectively lead and trail the vector B1. The vector sum $-(A1+C1)$ has the same phase angle as the vector B1 and occurs between the vectors A1,C1, and the vector sum $2B-(A+C)$ is
- 30 shown superimposed on the vector B1. The vector sum $A1-C1$ occurs between the vectors A1,B1 at an angle of 90 degs. with the vector B1, thus signifying the sine and cosine relationship between the terms $2B-(A+C)$ and A-C. Said 90 deg. relationship is preserved so long as the
- 35 vectors A1,C1 respectively lead and trail the vector B1 by like amounts, and this relationship is not disturbed

(within reasonable limits) by the absolute values of the phase angles between the vectors A_1, C_1 and C_1, B_1 . Also the circuit operates to compensate for phase errors so long as these errors are uniform, i.e. so long as the
5 vectors A_1 and C_1 lead and trail the vector B_1 by like amounts as mentioned herein above.

Reference is now made to how the apparatus copes with errors which may arise from manufacturing tolerances. It
10 will be clear that since the axes l_3R intersect at the common point $30P$ so that the region 30 is common to the three phase units 46 , the apparatus according to this invention is substantially immune to errors due to variations in reflectance or phase differences between
15 different portions of the scale. Also the scale 11 can be narrow in the Y -direction compared to a scale where three or perhaps four phase units require separate regions of the scale spaced in the Y -direction.

20 Regarding a yaw misalignment and consequent moire and phase errors, a yaw error would exist if the angular position of the read head 10 relative to the scale 11 about a Z -axis, e.g. the axis l_2Z , is such that the lines $17, 37, 47$ are not parallel. This would result in a moire
25 error, i.e. in the period of the moire fringes becoming finite, and would result in a corresponding change in the phase separation of the modulations M . However, since the axes l_3R intersect at the common point $30P$ the arrangement is optically equivalent to each unit 46
30 lying, notionally, on the axis l_2Z . Hence the phase separation between the modulations M remain unchanged.

A tolerance in the stand-off of the read head, i.e. in the spacing of the read head 10 and the scale 11 in the
35 Z -direction, may result in the common point $30P$ not lying exactly at the plane 18 . As a result, since the emitters

and receivers are aligned in the X-direction, there is produced a phase error by triangulation. This condition can be eliminated or reduced by arranging the emitters and receivers along respective lines in the Y-direction instead of in the X-direction as shown in Fig. 5. This results in the axes 13R not intersecting the plane 18 at the same point 30P but the intersections occur at three points one of which is on the axis 12Z while the other two are spaced to opposite sides thereof in the Y-direction so that there can be no phase error. However, when the emitters and receivers are so aligned, a yaw misalignment will produce moire fringes of finite period with a consequent occurrence of equal phase errors between adjacent pairs of the modulations M. This condition can be tolerated because equal phase errors can be eliminated by the circuit 50 as mentioned above.

Referring to Fig. 6, there is shown apparatus similar to that shown in Figs. 1-4 but applied to a transmissive scale 211. The apparatus comprises three phase units 246 wherein three light emitters 15 illuminate a first collimating lens 212 which produces collimated beams 213 converging to a common region 30 from which the beams emerge as emergent beams 214 which are focussed by a focussing lens 212F on to respective light receivers 225. Gratings 235, 245 in the beams 213, 214 produce light modulations substantially as described with reference to Figs. 1 to 4. The lens 212 is common to the group of emitters 15. The lens 212F is common to the group of receivers 25. Either group could have individual lenses for its emitters or receivers as the case may be.

Referring to Figs. 7 and 8, the apparatus comprises three phase units 346 wherein three light emitters 315 illuminate respective collimating lenses 312 defining individual collimating systems for the respective units.

The lenses 312 produce collimated beams 313 along respective convergent axes 313R converging on to a common region 30 on a scale 11 which reflects the light in the form of beams 314 and through focussing lenses 312F on to
5 respective receivers 325. Gratings 335, 345 beams 313, 314, produce light modulations substantially as described with reference to Figs. 1-4.

Referring to Figs. 9 and 10, apparatus comprises three
10 phase units 446 having emitters 15 and receivers 25 arranged substantially on a common line 15/25X extending in the X-direction or, as shown in broken lines, substantially on a common line 15/25Y extending in the Y-direction. It will be seen that the emitter-receiver
15 pair 15, 25 situated nearest the axis 12Z may be situated directly adjacent one another as shown.

It will be understood that the emitters may each be constituted by one end of a light transmitting fibre
20 whose other end is connected to the appropriate receiving diode. Regarding the emitter/receiver pair situated nearest the axis 12Z, this pair may comprise a concentric emitter/receiver device or may be constituted by the end of a single light-transmitting fibre concentric with the
25 axis 12Z and adapted to transmit both the incident and the reflected light.

CLAIMS:

1. Opto-electronic scale reading apparatus comprising a scale (11;211) defined by spaced lines (17),

5 a read head (10), the read head (10) and the scale (11;211) being relatively movable in the direction of spacing of the lines (17)

a plurality of units (46;246;346;446) embodied in the read head (10) and each comprising

10

a light emitter (15) for illuminating a region (30) of the scale (11;211),

15 a light receiver (25) for receiving light from the illuminated region (30),

grating means (35,45) arranged in the light path between the emitters (15) and the receivers (25) for producing in respect of each unit (46;246;346;446) a light modulation
20 (M) corresponding to the relative movement of the scale (11;211) and the read head (10), wherein the light modulations (MA,MB,MC) of the respective units (46;246;346;446) occur in phase-shifted relationship,

25 characterised in that

the units (46;246;346;446) are positioned so that their respective light emitters (15) illuminate a region (30) of the scale (11;211) which is substantially common to
30 all said emitters (15).

-11-

2. Apparatus according to claim 1, comprising means (12;312) associated with each said emitter (15) for producing a beam 13 of collimated light and arranged so that the beams (13) pertaining to the respective emitters
5 (15) extend along axes (13A) which intersect substantially at a common point (30P).

3. Apparatus according to claim 1, comprising an optical collimating system (12;212;312) having an axis
10 (12Z;212Z;312Z) wherein the emitters pertaining to the respective units (46;246;346;446) are situated at the focussing side of the system (12;312) in positions spaced from said axis (12Z) and so that collimated beams (13) generated by the emitters (15) at the collimating side of
15 the system (12) intersect substantially at a common point (30P).

4. Apparatus according to claim 3 wherein the collimating system (12) comprises a collimating lens (12)
20 which is common to at least one of the groups defining respectively the emitters (15) and the receivers (25).

5. Apparatus according to claim 3 wherein the collimating system (312) comprises individual collimating
25 lenses (312) for at least one of the groups defining respectively the emitters (15) and the receivers (25).

6. Apparatus according to claim 4 or claim 5 wherein the scale (11) is reflective and the receivers (25) are
30 situated at the same side of the scale (11).

7. Apparatus according to claim 4 or claim 5 wherein the scale (211) is transmissive and the emitters (15) and receivers (25) are situated at opposite sides of the
35 scale (211).

8. Apparatus according to any one of the preceding claims wherein the emitters (15) pertaining to the respective units (46;246;346;446) are arranged along a line (15X) parallel to the direction (X) of spacing of the scale lines (17).

9. Apparatus according to any one of claims 1 to 8 wherein the emitters (15) of the respective units (46;246;346;446) are spaced along a line (15Y) at right angles to the direction (X) of the spacing of the scale lines (17).

10. Apparatus according to any one of the preceding claims comprising three said units (46;246;346;446) and means (5) for establishing signals (sine, cosine) defining a quadrature relationship between the phases of said modulations (M).

1/6

FIG. 1.

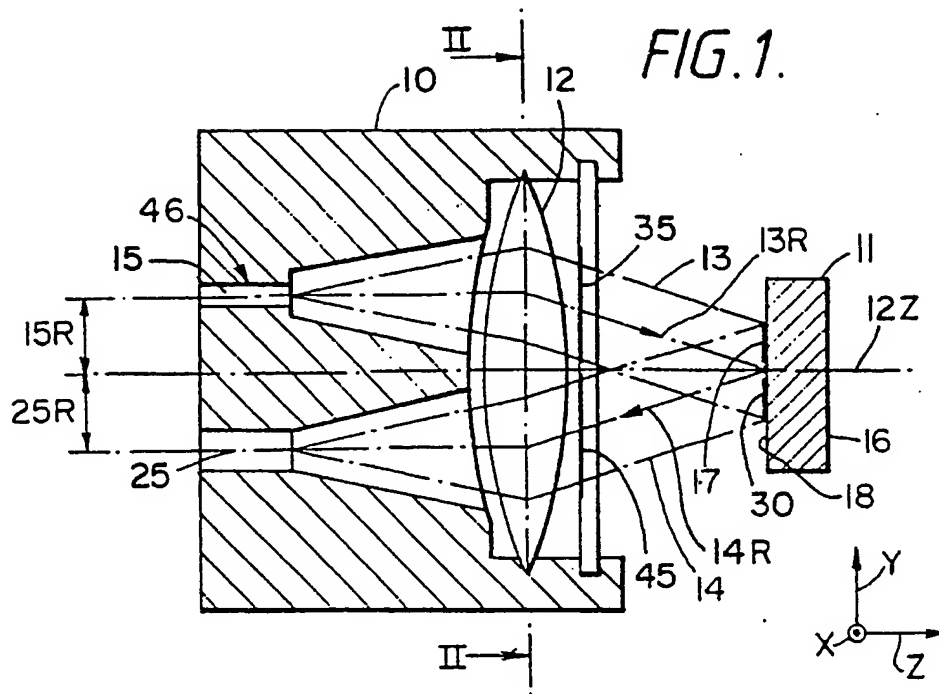
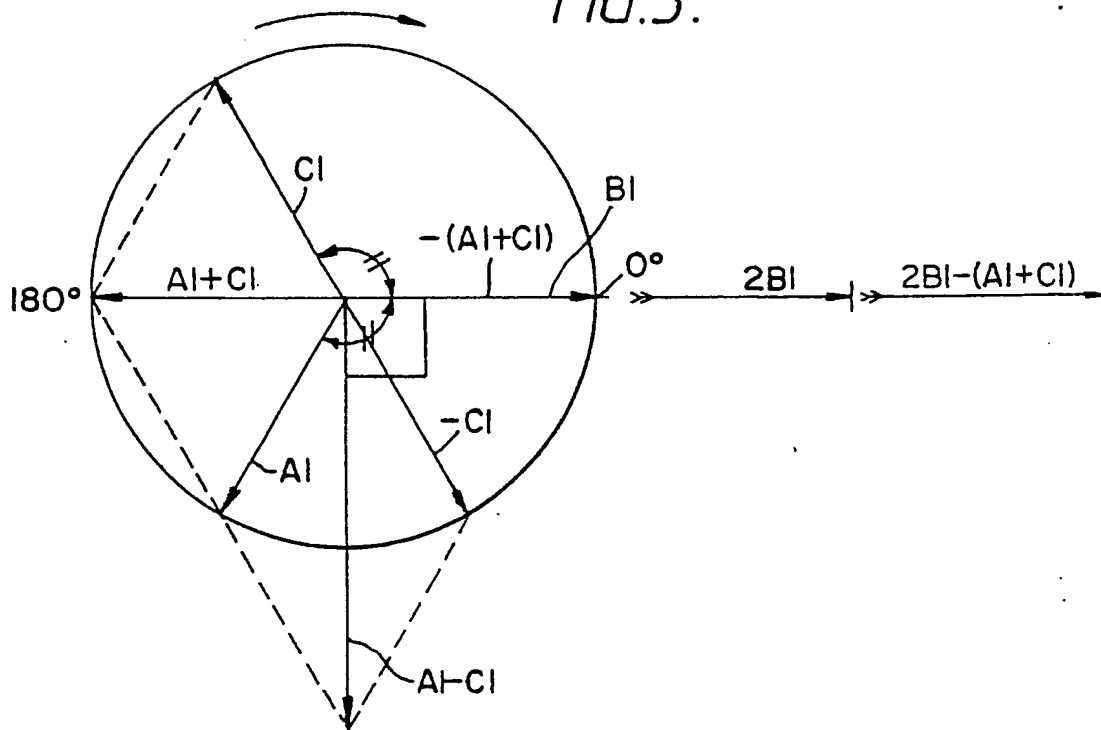


FIG. 3.



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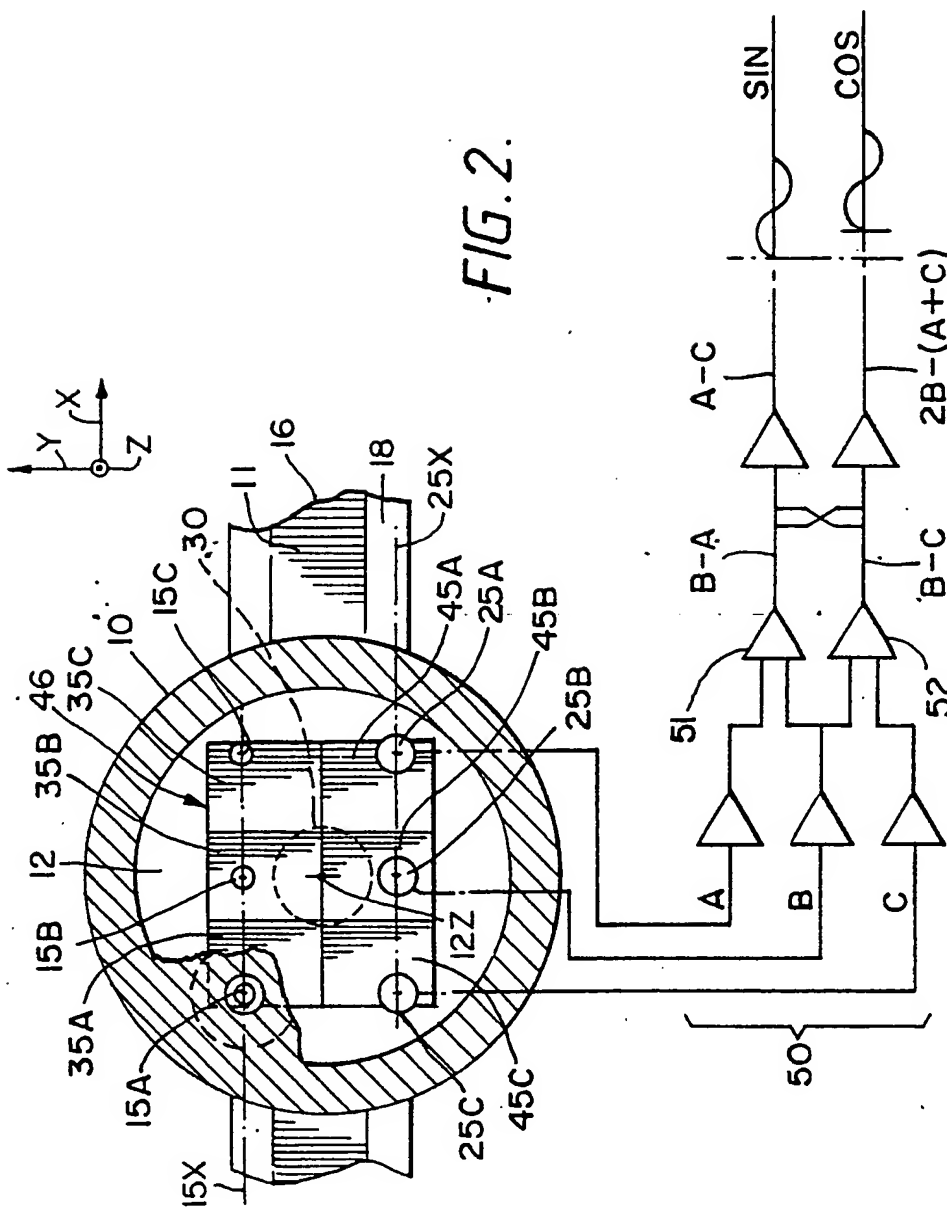
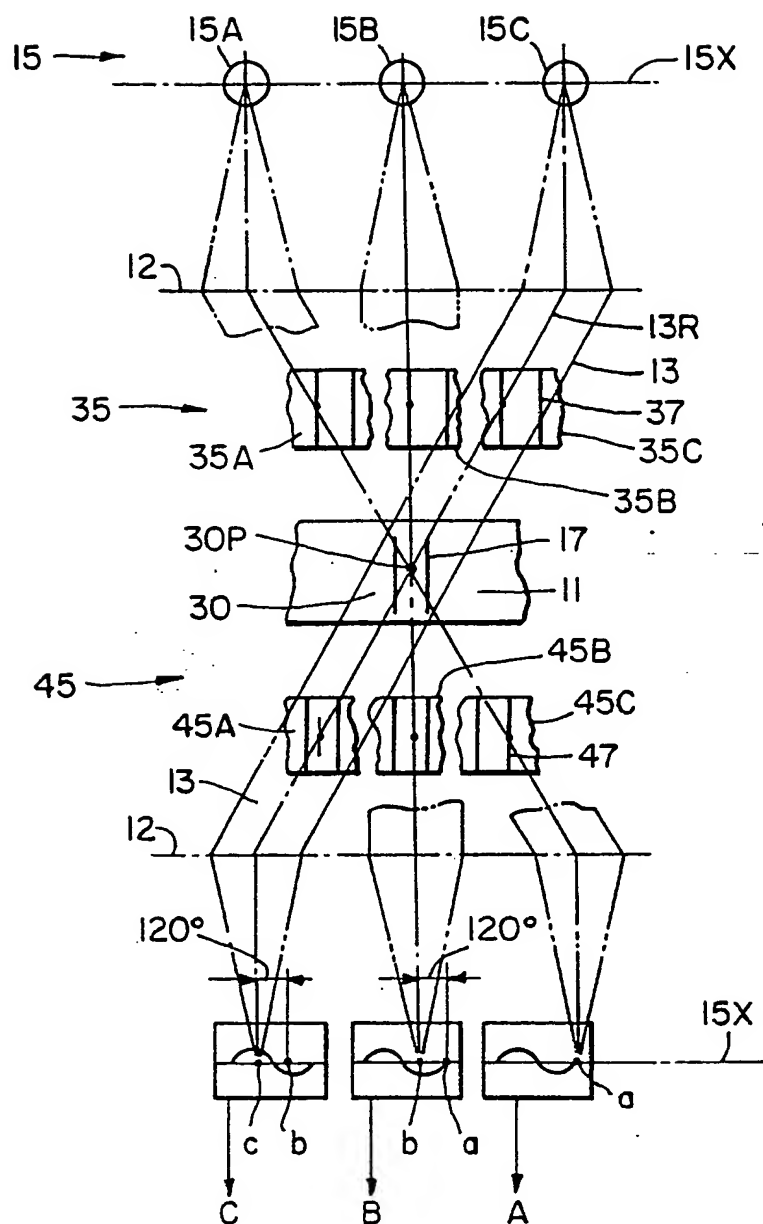
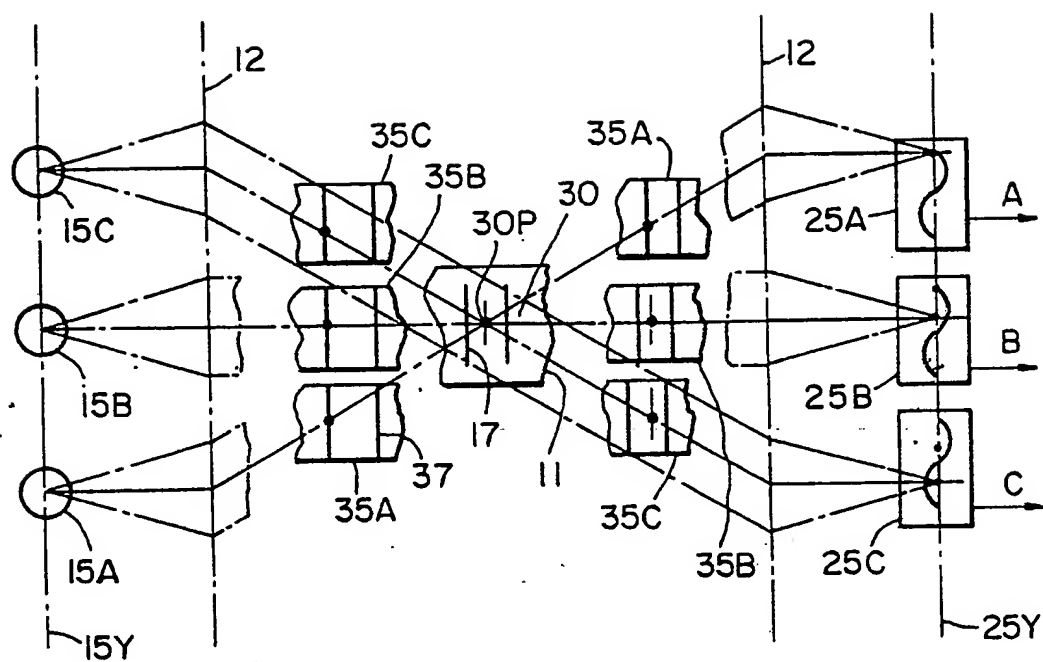


FIG. 4.

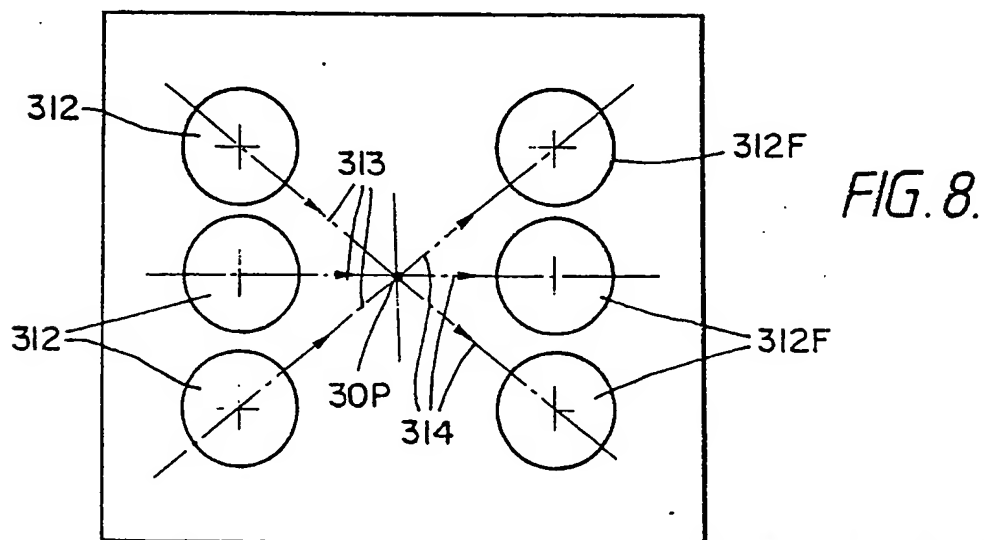
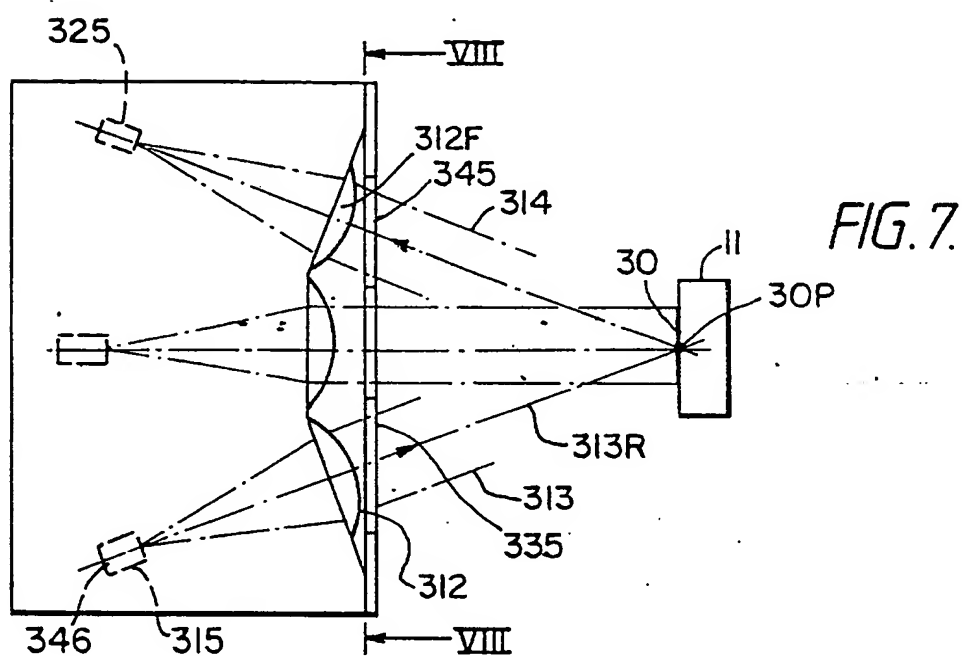
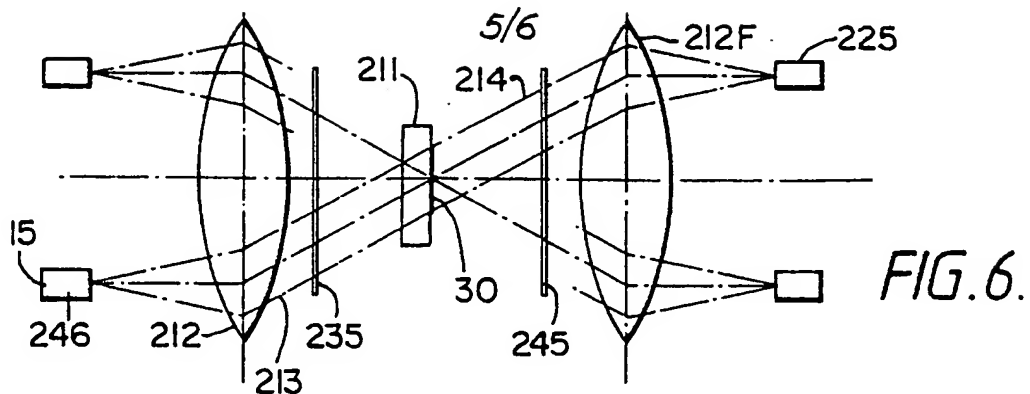


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FIG. 5.



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6/6

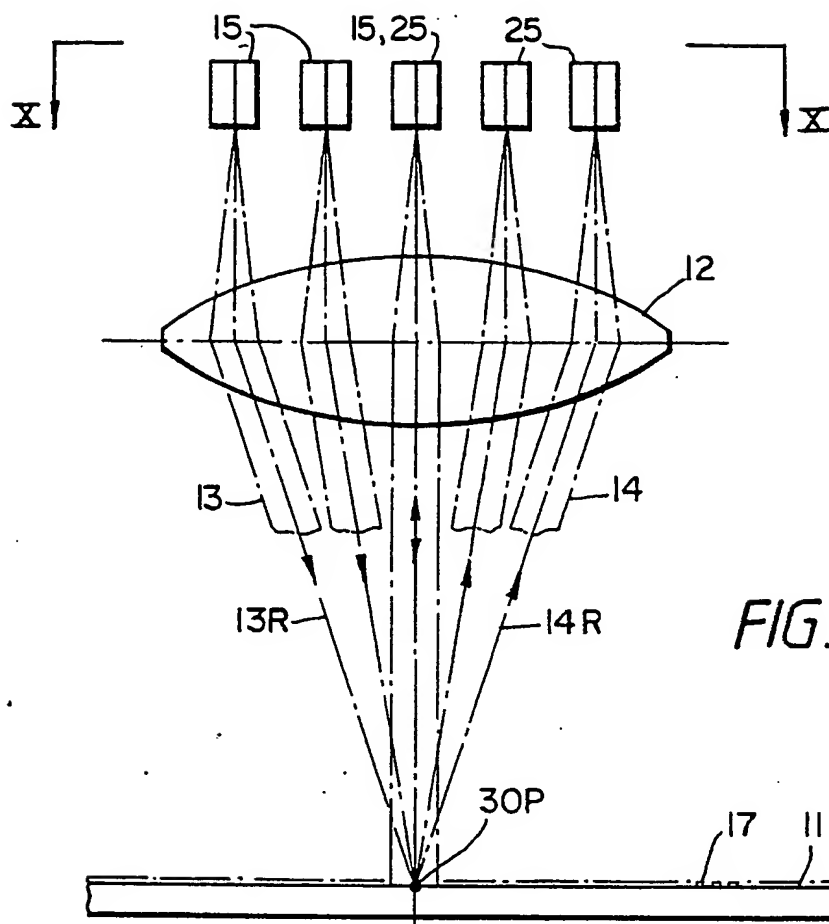


FIG. 9.

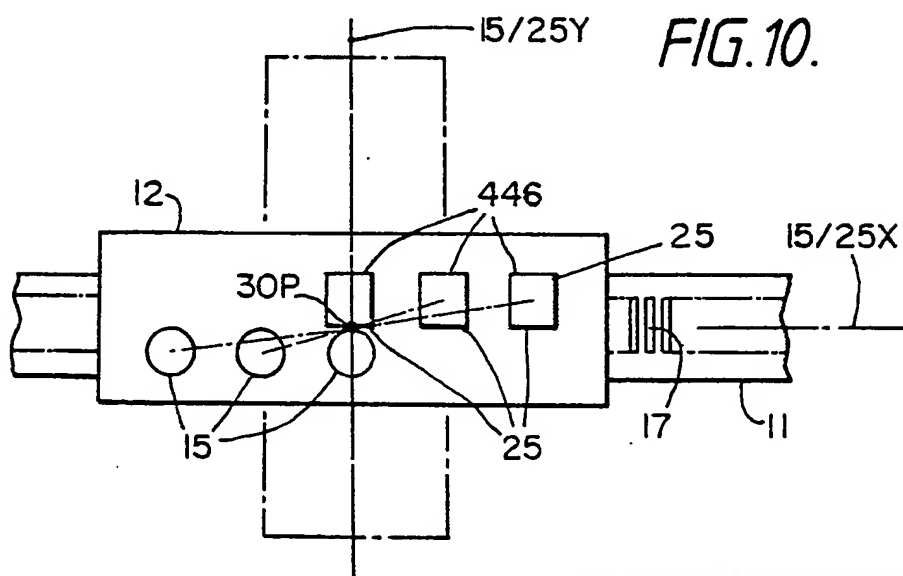


FIG. 10.

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INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 87/00434

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC ⁴ : G 01 D 5/34; G 01 D 5/38		
II. FIELDS SEARCHED		
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Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	Werkstatt & Betrieb, volume 112, no. 11, November 1979, (Munich, DE), A.T. Shepherd: "Moiré-Streifen in der Messtechnik", pages 782-786 see page 785, paragraphs 4,6; figures 9,11	1-4,6,9, 10
X	Patent Abstracts of Japan, volume 10, no. 147 (P-460)(2204), 29 May 1986, see the whole abstract & JP, A, 61712 (TOUKIYOU SEIMITSU K.K.) 6 January 1986	1-4,7,9
X	US, A, 3344700 (D.G. BRAKE) 3 October 1967 see figures 3,4,7; column 4, line 65 - column 5, line 45; column 6, lines 36-47	1-4,6,8
X	DE, A, 2720195 (FERRANTI LTD) 17 November 1977 see figures 1,2; introduction; page 6, paragraph 2 - page 8, paragraph 2; page 9, paragraphs 1,2	1-4,6,9,10

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ANNEX TO THE INTERNATIONAL SEARCH REPORT

INTERNATIONAL APPLICATION NO. PCT/GB 87/00434 (SA 17718)

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 3344700		None	
DE-A- 2720195	17/11/77	GB-A- 1525049	20/09/78
		US-A- 4115008	19/09/78
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